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EXPERIMENTAL STUDY ON STRUCTURAL BEHAVIOUR OF BEAM COLUMN JOINT USING GEO-POLYMER CONCRETE

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ABSTRACT

Concrete usage around the world is second only to water. Ordinary Portland cement (OPC) is conventionally used as the primary binder to produce concrete. The environmental issues associated with the production of OPC are well known. The amount of the carbon dioxide released during the manufacture of OPC due to the calcinations of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced. In addition, the extent of energy required to produce OPC is only next to steel and aluminium. On the other hand, the abundant availability of fly ash worldwide creates opportunity to utilize this by-product of burning coal, as a substitute for OPC to manufacture concrete. So, one of the ways to produce environmental friendly concrete is to reduce the use of Ordinary Portland Cement by using other forms of binders to make concrete. In geo-polymer concrete, the silicon and the aluminium in the low-calcium (Class F) fly ash react with an alkaline liquid that is a combination of sodium silicate and sodium hydroxide solutions to form the Geo-polymer paste that binds the aggregates and other unreacted materials. Based on the previous studies and laboratory experience, it is found that the cost of geo-polymer concrete per cubic meter is approximately the same as that of Portland cement concrete. But on considering the impact of the possible carbon dioxide emission and cost of production of cement and the environmental advantage of utilization of fly ash, the geo-polymer concrete may prove to be economically and environmentally advantageous.

Key words: Geo-Polymer, Framed Structure, Molarities, and Strength

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1. INTRODUCTION

Geo-polymer concrete is a concrete which does not utilize any Portland cement in its production. Geo-polymer concrete is being studied extensively and shows promise as a substitute to Portland cement concrete. Beam column joints is a critical member in structural system and during earthquakes, structural elements must be able to dissipate a great amount of energy to ensure the structural integrity of the building to avoid collapse. Due to high shearing force and environmental effects on the beam column joints they tend to be weaker portion of a framed structure. Hence it is so much necessary to increase its strength. In the present study, the role of geo polymer concrete with various molarities of 8M, 10M, 12M, 14M, 16M in the behavior of geo polymer concrete beam column joints were studied under cyclic loading. The influence of geo polymer on the ultimate load, first crack load, deflection of beam column joints was studied.

2. MIXING

The main objectives of the preliminary laboratory work were:

- To familiarize with the making of fly ash based geo-polymer concrete.
- To observe the behavior of the fresh fly ash based geo-polymer concrete.
- To understand the basic mixture proportioning of fly ash based geo-polymer concrete.
- Ratio of sodium silicate solution to sodium hydroxide solution, by mass of 0.4 to 2.5. This ratio was fixed at 2.5 all the mixtures because the sodium silicate solution is considerably cheaper than the sodium hydroxide solution.
- Molarity of sodium hydroxide (NaOH) solution is in the range of 8M to 16M. The compressive strength of the geo-polymer concrete increases with the molarity.
- Ratio of activator solution to fly ash, by mass in the range of 0.3 and 0.4.
- Coarse and fine aggregates together contribute approximately 75% to 80% of the entire mixture by mass. This value is similar to that used in OPC concrete.
- Super plasticiser is in the range of 0% to 2% of fly ash, by mass and fixed to a ratio of 1% by mass of fly ash in the present work.

Extra water required is fixed by conducting the standard slump test and compaction factor tests. A slump value of 90-120mm and compaction factor of 0.9 is maintained throughout the study. The total mass of water is the sum of the mass of water contained in the sodium silicate solution. The mass of geo-polymer solids is the sum of the mass of fly ash, the mass of sodium hydroxide solids, and the mass of solids in the sodium silicate solution (i.e. the mass of Na_2O and SiO_2).The calculations of water to geo-polymer solids ratio by mass of mixtures with 16M NaOH solution .In ordinary Portland cement concrete, water in the mixture chemically reacts with the cement to produce a paste that binds the aggregates. In contrast, the water in a low-calcium fly ash based geo-polymer concrete mixture does not cause a chemical reaction. However, laboratory experience showed that water content in the geo-polymer concrete mixture affected the properties of concrete in the fresh state as well as in the hardened state. Past studies show that the compressive strength of geo-polymer concrete decreased as the ratio of water to geo-polymer solids by mass increased.

2. MIX PROPORTION

2.1 CALCULATION

Unit weight of geo polymer concrete	=	2400 kg/m^3
Mass of combined aggregates	=	77% of 2400
	=	1848 kg/m^3
Coarse aggregate	=	70% of 1848
	=	1293.6 kg/m^3
Fine aggregate	=	30% of 1848
	=	554.4 kg/m^3
Mass of alkaline liquid and fly ash	=	2400-1848
	=	552 kg/m^3
Assume,		
Alkaline liquid/Fly Ash	=	0.4
Mass of Fly Ash	=	552/1.4
	=	394.28 kg/m^3
Mass of alkaline liquid	=	552-394.28
	=	157.72 kg/m^3
Assume,		
Sodium silicate/sodium hydroxide	=	2.5
Mass of sodium hydroxide = 157.72/3.5		
	=	45.06 kg/m^3
For 8 Molar,		
NAOH solid	=	26.23% of 63.088
	=	11.819 kg/m^3
Water	=	45.06-11.819
	=	33.241 kg/m^3
Mass of sodium silicate	=	157.72-45.06
	=	112.66 kg/m^3
Mass of sodium silicate gel	=	44.1% of 112.66
	=	49.683 kg/m^3
Mass of water	=	62.977 kg/m^3
Water/ geo-polymer solid	=	(62.977+33.241)/
(394.28+11.819+49.683)		
	=	0.211
Alkaline solution / Fly ash Ratio	=	0.4
Sodium silicate/ Sodium hydroxide sol ratio = 2.5		
BASF Rheobuild 924KL (1% of Fly ash) = 4.25		

The solids constituents of the fly ash-based geo polymer concrete, i.e. the aggregates and the fly ash, were dry mixed manually for about three minutes. The liquid part of the mixture, i.e. the sodium silicate solution, the sodium hydroxide solution, extra water and the super

plasticizer were premixed & then added to the solids. The wet mixing usually continued for another four minutes.

3. RESULTS AND DISCUSSIONS (LOAD DEFLECTION BEHAVIOUR)

The deflection of the specimen in each increment of load was measured. The deformations due to the elastic rotation of the columns are deducted from the measure values at the tip of the beam so the deformation due to elastic behavior of the joint is included in the corrected deformations, the typical load deflection curve for Conventional Concrete (CC) and geo-polymer specimens is shown from Fig.3.1 to Fig.3.5

Table-3.1 Deflection factor for conventional concrete specimen

No of cycles	Load in kN	Max Deflection in mm (conventional)	
		Forward	Reverse
I	20	9.78	5.23
II	35	16.76	12.36
	40	-	-
III	30	-	-
	35	-	-

F-Forward; R-Reverse

Table-3.2 Deflection factor for GP2, GP3, GP4 and GP5 concrete

No of cycle	Load In kN	Max Deflection in mm							
		GP-2		GP-3		GP-4		GP-5	
		F	R	F	R	F	R	F	R
I	20	7.23	6.8	7.56	6.8	8.5	5.8	8.4	6.8
II	35	11.2	10.87	-	-	-	-	-	-
	40	-	-	11.82	10.64	9.2	7.8	12.36	9.4
III	30	-	-	-	-	-	-	10.81	-
	35	-	-	11.08	-	-	-	-	-
	40	-	-	-	-	10.12	-	-	-

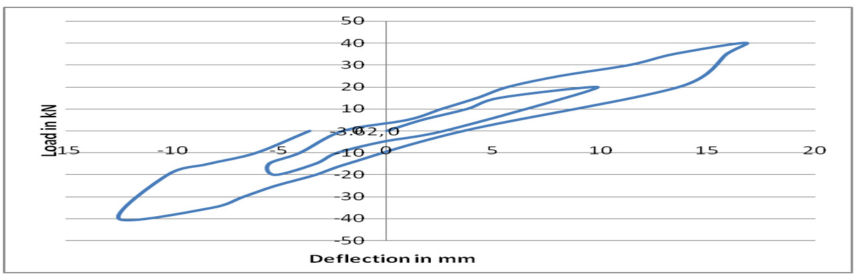

Figure 3.1 Load Deflection Curve of Conventional

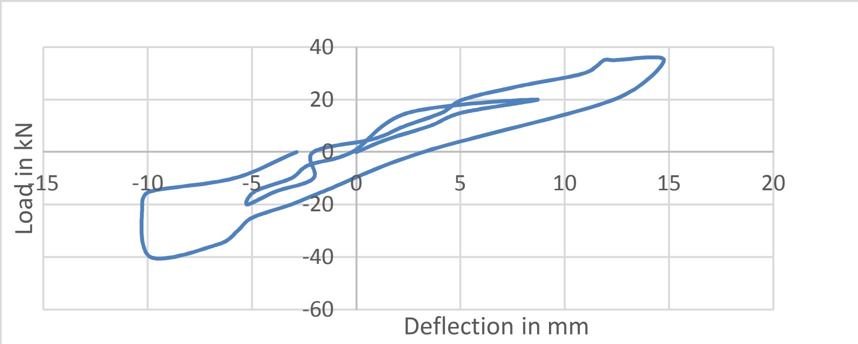

Figure 3.2 Load Deflection Curve of GP-02

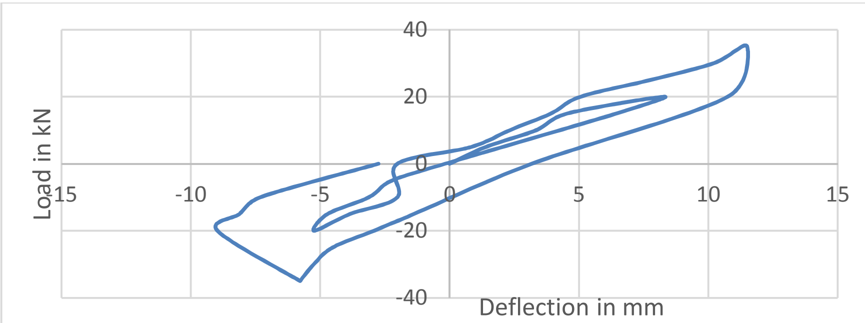

Figure 3.3 Load Deflection Curve of GP-03

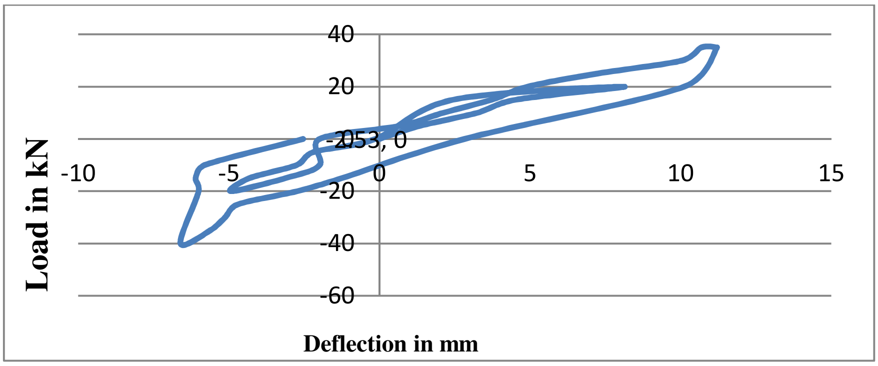

Figure 3.4 Load Deflection Curve of GP-04

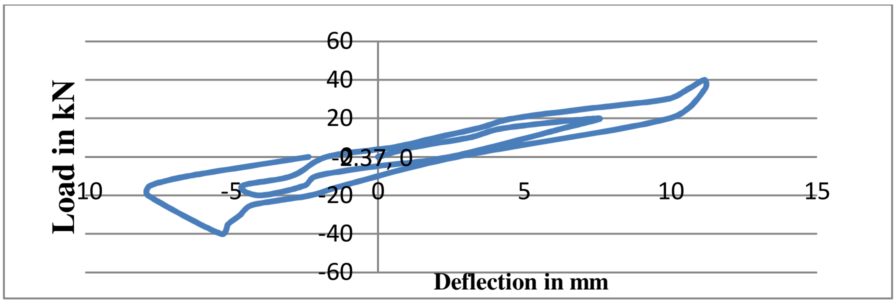

Figure 3.5 Load Deflection Curve of GP-05

3.1. DUCTILITY

The ductility is defined as the ratio between maximum and yield displacement. The load displacement graph is used to determine the ductility. The yield displacement is defined from the line drawn between origin and 50% load capacity point of the curve shown in Fig.3.6.This

line extend to intersect the 80% load carrying capacity horizontal line and the corresponding displacement is the yield displacement (d_y). The displacement corresponding to ultimate load (P_u) is considered as ultimate load deflection (d_u) (Jamal et al., 2005). The ductility factor of the specimen under static load is shown in Table 3.3

$$\text{Ductility factor} = \frac{\text{Deflection at ultimate load } (P_u)}{\text{Deflection at yield load } (P_y)} = \frac{d_u}{d_y}$$

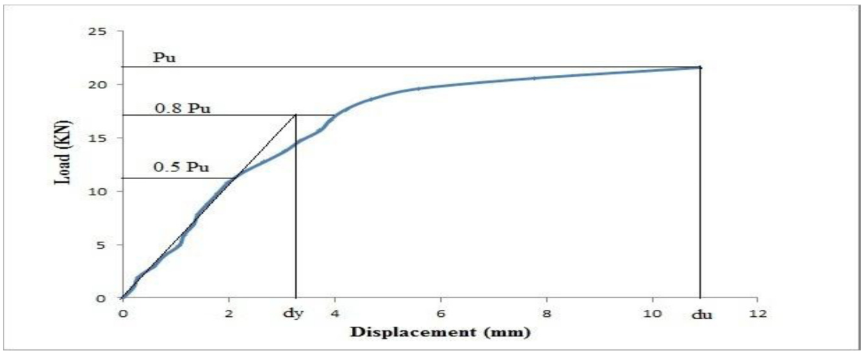

Figure 3.6 Determination of Ductility Factor

The geo-polymer concrete and conventional concrete ductility factor comparison is given below in table 3.3 &3.4

Table 3.3 Ductility Factor for conventional concrete

No of cycles	Load in kN	Ductility factor(μ) (conventional)	
		Forward	Reverse
I	20	1.66	1.62
II	35	4.23	5.2
	40	-	-
III	30	-	-
	35	-	-

Table 3.4 Comparison of ductility factor for GP2, GP3, GP4 and GP5 concrete

No of cycles	Load in kN	Ductility Factor(μ)							
		GP-2		GP-3		GP-4		GP-5	
		F	R	F	R	F	R	F	R
I	20	1.2	1.26	1.28	1.98	2.6	2.8	3.2	3.46
II	35	5.16	5.74	-	-	-	-	-	-
	40	-	-	3.86	5.24	4.2	5.2	4.8	5.0
III	30	-	-	4.0	-	-	-	5.2	-
	35	-	-	-	-	-	-	-	-
	40	-	-	-	-	6.9	-	-	-

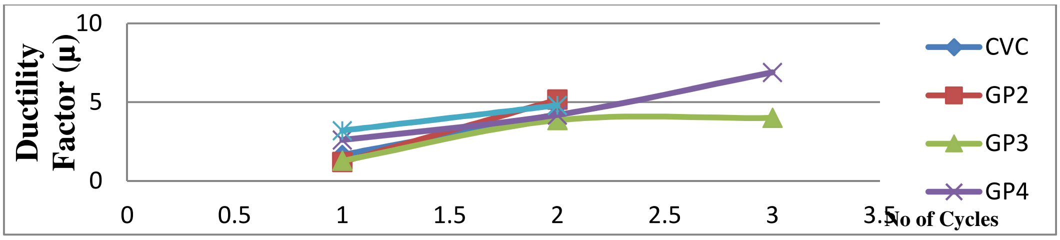

Figure 3.7 Forward cyclic load Vs Ductility behavior of CVC GP2, GP3, GP4 and GP5

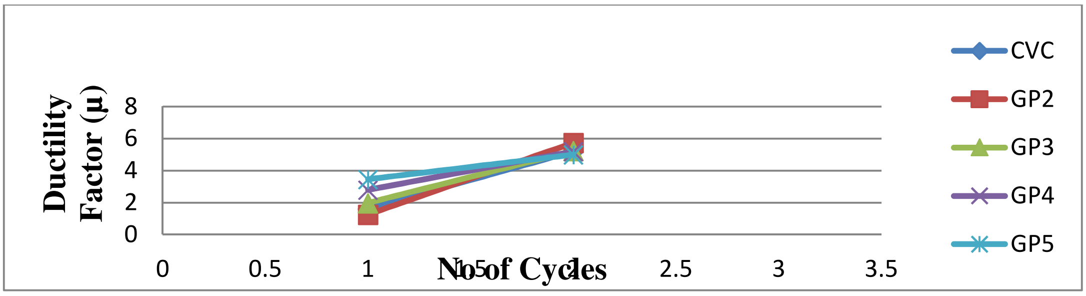

Figure 3.8 Reversed cyclic load Vs Ductility behavior of CVC GP2, GP3, GP4 &GP5

It was observed that Conventional beam column joint has lower ductility. The addition of 14M geo-polymer concrete (GP4) increases the ductility factor to 1.6 times of the conventional mix (M30). Similarly GP2, GP3and GP5 which has increase the ductility factor 0.8, 1.35 and 1.3 times respectively

3.3. ENERGY ABSORBTION CAPACITY

The energy absorption capacity under cyclic load is shown in Table 3.5.From Table 3.5 it may be observed that addition of alkaline solution increases the energy absorption capacity in both geo-polymer concrete and conventional beam column joint. In conventional specimens the increase in energy absorption capacity was 30% and 64% and in geo-polymer specimens 38% and 70% for 14M and 16M alkaline solutions additions respectively.

Table 3.5 Energy Absorption Capacity of conventional concrete

No of cycles	Load in kN	Energy Absorption in kN. mm(conventional)	
		Forward	Reverse
I	20	11	14
II	35	41	36.5
	40	-	-
III	30	-	-
	35	-	-

Table 3.6 Comparison of Energy absorption capacity for GP2, GP3, GP4 and GP5

No of cycles	Load in kN	Energy absorption in kN mm							
		GP-2		GP-3		GP-4		GP-5	
		F	R	F	R	F	R	F	R
I	20	15	19.5	17	23.25	21	26.25	12	16
II	35	45	42	-	-	-	-	-	-
	40	-	-	38	47.2	43.8	58.6	42	38
III	30	-	-	-	-	-	-	130	-
	35	-	-	87	-	-	-	-	-
	40	-	-	-	-	98	-	-	-

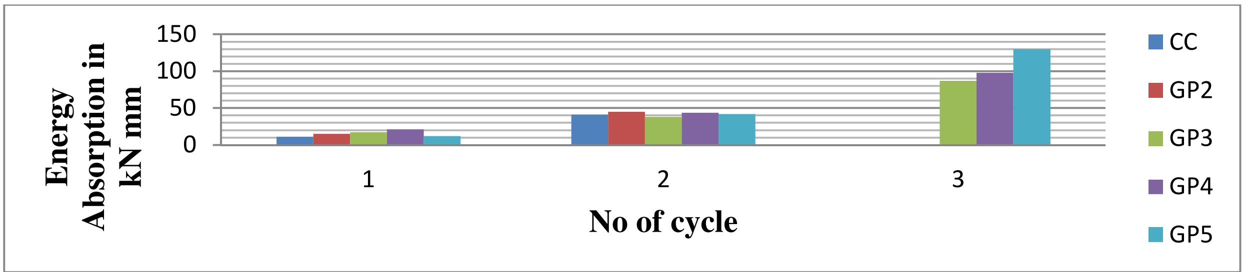

Figure 3.9 Energy absorption capacity of GP2, GP3, GP4 and GP5 under forward cyclic loading.

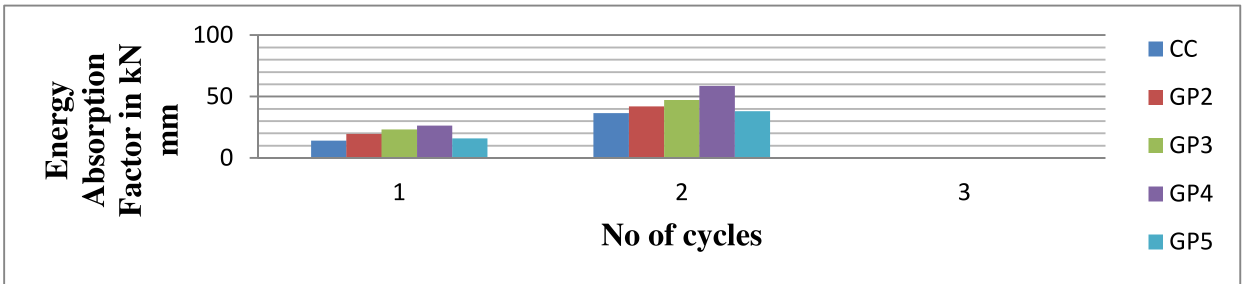

Figure 3.10 Energy absorption capacity of GP2, GP3, GP4 and GP5 under reversed cyclic loading

3.4. CRACK PATTERN

The crack pattern of conventional and geo-polymer beam column joint under cyclic loading. The entire beam column joint showed the same failure pattern with first crack developed at joint face in cyclic loading. In the first and second cycle no crack was developed anyone of the specimen. Initiation and propagation of crack was observed in third cycle. But during unloading propagation of crack was stopped. On further loading when specimen was loaded to failure, cracks started to widen and the specimen failed at ultimate load

3.5. STIFFNESS DEGRADATION

In the case of reinforced beam column joints the stiffness of the joint gets reduced when the joint was subjected to cyclic loading. This reduction in stiffness is due to initiation of micro cracks inside the joint and will sometimes lead to the fatigue limit of the materials. From

Fig.3.12 it was understood that the beam column joint using geo-polymer concrete show higher stiffness. Thus geo-polymer concrete shows higher stiffness and lesser stiffness degradation than the conventional mix.

Table 3.7 stiffness factor of conventional concrete

No of cycle	Load in kN	Stiffness Factor in kN/mm(conventional)	
		Forward	Reverse
I	20	8.4	7.52
II	35	4.23	6.4
	40	-	-
III	30	-	-
	35	-	-

Table 3.8 Stiffness factor for specimens GP2, GP3, GP4 and GP5

	Load in kN	Stiffness Factor in kN/mm							
		GP-2		GP-3		GP-4		GP-5	
		Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse
I	20	9.24	8.3	10	8.4	11.4	9.3	8.3	7.4
II	35	4.26	4.4	-	-	-	-	-	-
	40	-	-	8.4	5.6	6.8	5.82	5.4	4.6
III	30	-	-	-	-	-	-	4.8	-
	35	-	-	3.8	-	-	-	-	-
	40	-	-	-	-	4.2	-	-	-

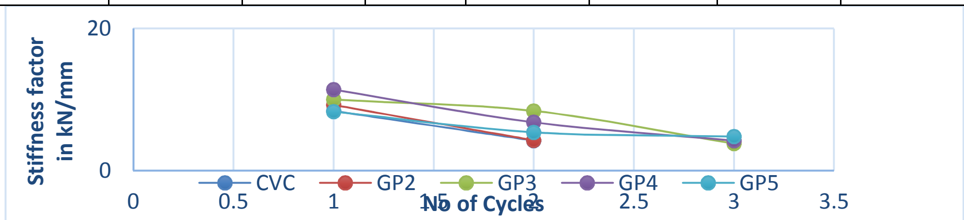

Figure 3.12 Stiffness factor for the CVC, GP2, GP3, GP4 & GP5 specimens under Forward cyclic loading

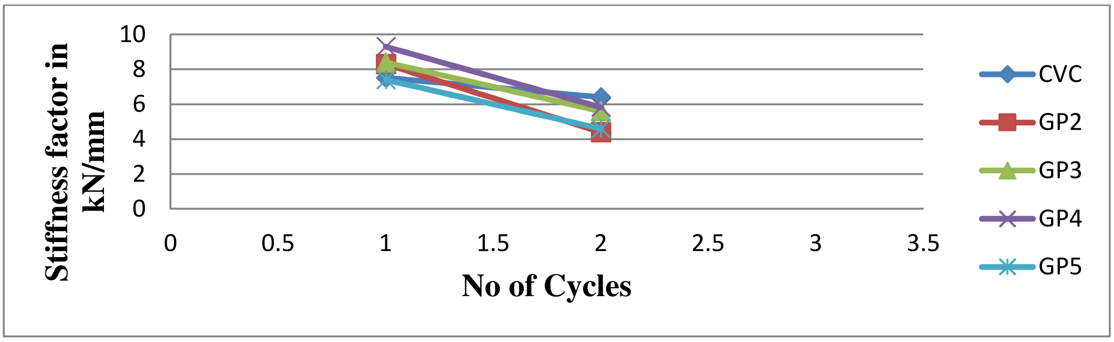

Figure 3.13 stiffness factor for the CVC, GP2 to GP5 specimens under reversed cyclic loading

4. CONCLUSION

A new class of geo-polymeric binders is obtained with full replacement of cement with industrial waste fly ash which in turn produced an economical and environmental friendly concrete with less consumption of energy resources and carbon dioxide emission. The following conclusions have been drawn.

- Geo-polymer concrete is a good alternative for normal concrete. Geo-polymer can improve all the properties of hardened concrete and the major influence was in the improvement of structural behavior.
- Geo-polymer concrete increases the compressive strength by 30% compared to conventional concrete. In cyclic loading the increase in first crack load in geo-polymer by addition of 12M, 14M and 16M of concentration are corresponding increase in conventional.
- The load deflection characteristics of geo-polymer reinforced beam column joint were better than conventional concrete. The geo-polymer specimens showed better performance under cyclic loading. The ultimate load of geo-polymer increases by 32% compare to conventional concrete.
- In conventional method, specimens were subjected to cyclic loading. On comparing the ductility factor increases, in addition with concentration of various molarities of NaOH. Geo-polymer concrete increases the ductility factor to 1.6 times of the conventional mix.
- Under cyclic loading geo-polymer shows 3.17 times higher energy absorption capacity of conventional specimen. The geo-polymer concrete beam column joint shows higher stiffness.

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